Catalysis and Oxidation of Copper Calorimeters – Are we Over-Testing Material Samples?

Motivation:

- Arc-jet tests are the most important criteria for designing and accepting thermal protection systems (TPS). Their plasma plume is characterized by using a copper calorimeter according to ASTM practice [1] to measure heat flux, which is inserted into the stream.
- Full catalycity is assumed to convert measured heat flux to incident hot wall heat flux onto TPS.

Hypothesis:

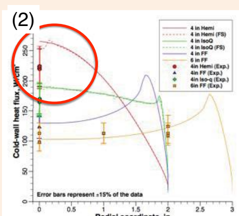
- During the measurement in Air plasma, oxidation occurs on the copper slug. This changes the catalycity value and causes the absorbed (reported) heat flux to be significantly lower than the incident heat flux.
- The value of the heat flux at which TPS are currently tested is thus higher than required, leading to over-dimensioning the TPS for a flight design.
- Literature shows that different copper oxides form, and their film thickness depends on temperature and time of exposure.

[1] ASTM E457-96 (Reapproved 2002) “Standard Test Method for Measuring Heat-Transfer Rate Using a Thermal Capacitance (Slug) Calorimeter.”

Evidence

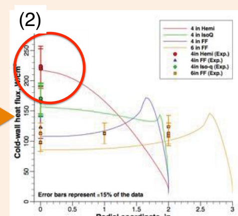
→ picture showing clear signs of oxidation on slug after exposure to plasma

(2)

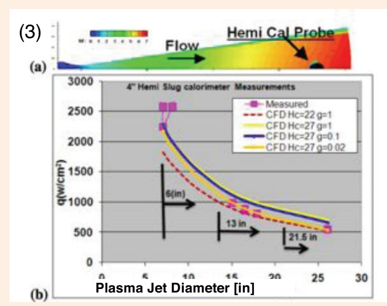


introducing catalycity < 1 for slug

(2)



(3)



(2) Courtesy of Dinsh Prahbu, ERC, data from AHF 295
(3) Imelda, Terrazas-Salinas, J. Enrique Carballo, David M. Driver, and John Balboni, AIAA 2010-5053

→experimental data overall is better matched when reducing the catalycity of the copper slug
→independent of nozzle diameter
→independent of radial position of slug

Proposed systematic study:

An effort is needed, which aims at providing a clear understanding of the oxidation effects on copper calorimeters exposed to various arc-jet test conditions and the direct impact oxidation has on the resulting catalytic coefficient.

1. Establish correlation between calorimeter surface (morphology/ chemistry) and catalytic properties of material.
   - pre-and post surface analysis of all materials to determine surface composition, thickness of oxide layer, crystal structure change, etc. (e.g. using XPS, TEM)
   - Use different materials (copper, platinum, nickel, gold, etc).
2. Develop a Chemistry Database for CFD generalized gas-surface interactions wall boundary conditions.
   - Combine experiments and simulations to populate gas-surface interaction kinetic database
3. Quantitatively assess catalycity-based error in heat flux used for high enthalpy testing of TPS.
   - Conduct systematic catalysis tests (using side-arm reactor investigations) before and after arc-jet plasma exposure to assess the error in the predicted hot wall heat flux values
   - Repeat for different calorimeter materials to rank catalytic effects and identify potential calorimeter material candidates for future use. Both CO2 and air environments proposed.

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